GLAST Flight Dynamics Peer Review

February 10, 2004

RFA's

- Provide all RFA's to John Lynch (John.P.Lynch@nasa.gov) by February 13th

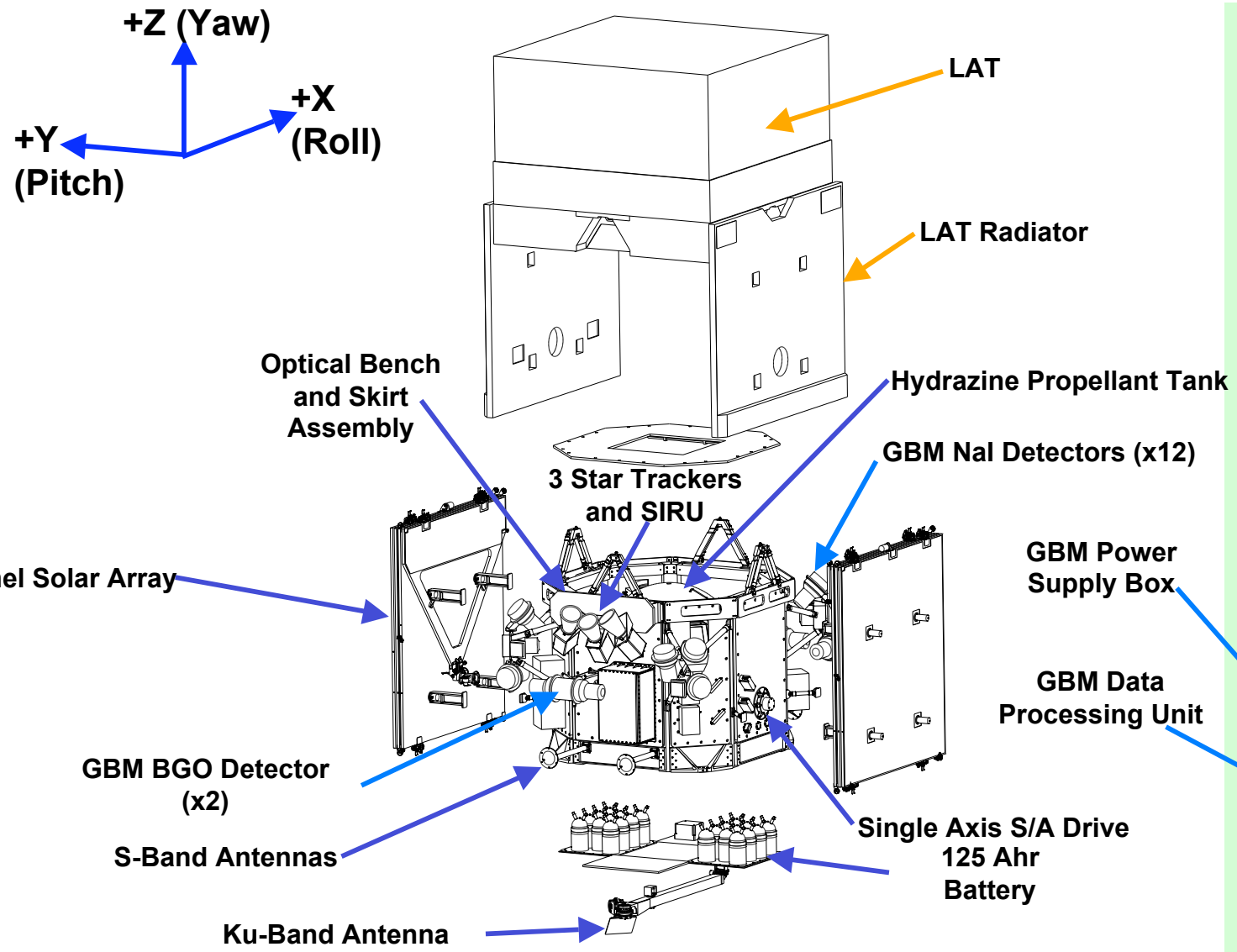
Purpose

- Provide an overview of Flight Dynamics operations for the GLAST mission
- Present Flight Dynamics requirements for the GLAST mission
- Present results of Flight Dynamics analyses performed to date
- Identify open items and issues

Introduction

- GLAST is scheduled for launch in February 2007 from a Delta 7920-H10 from KSC
- Spacecraft mass ~4627 kg
- Orbit Determination (and timing) onboard using GPS; redundant General Dynamics Viceroy receivers
- Attitude Determination onboard using star trackers, gyros, and a Kalman Filter
- Mission lifetime of 5 years (10 year goal)

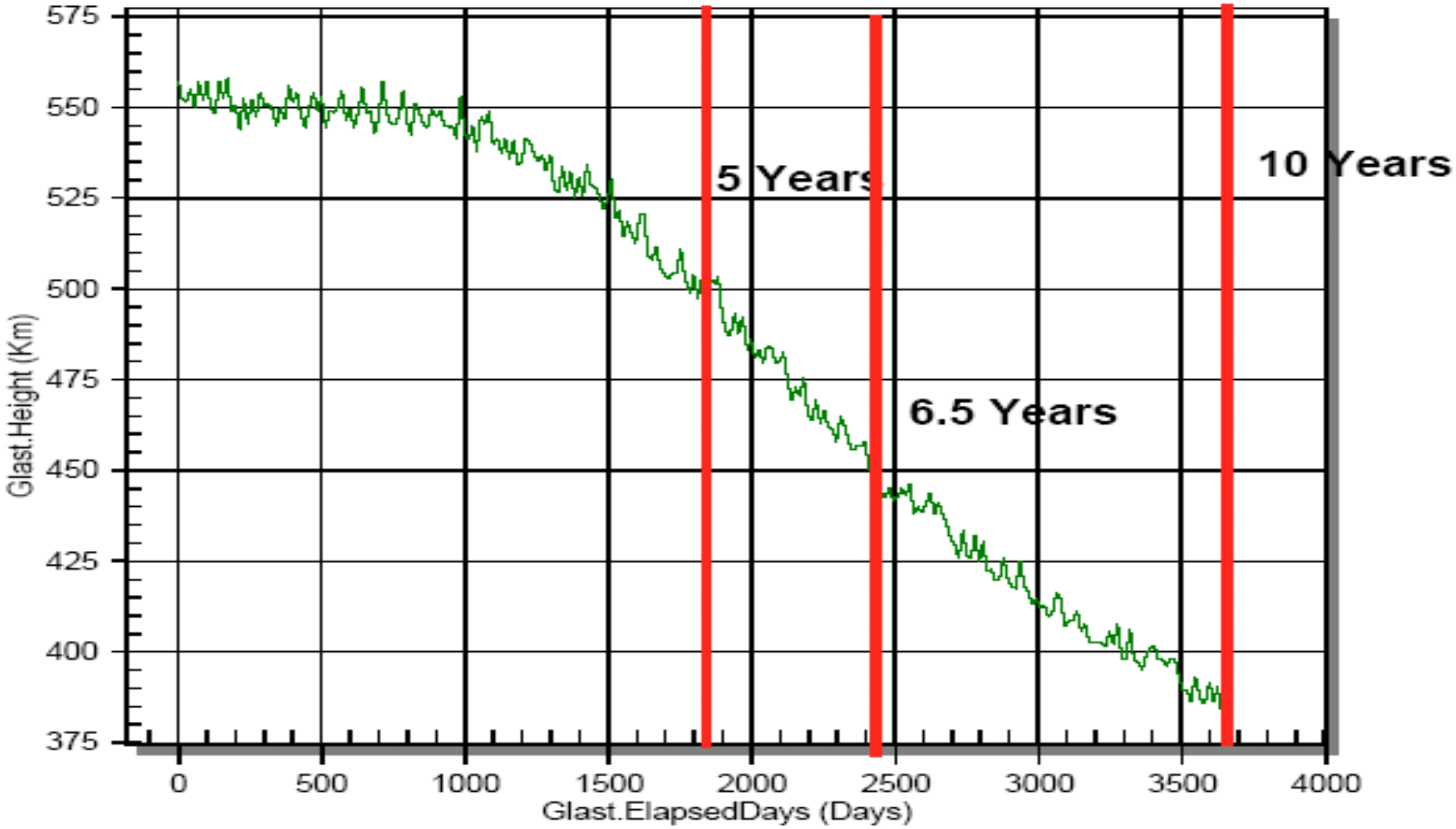
Observatory Layout



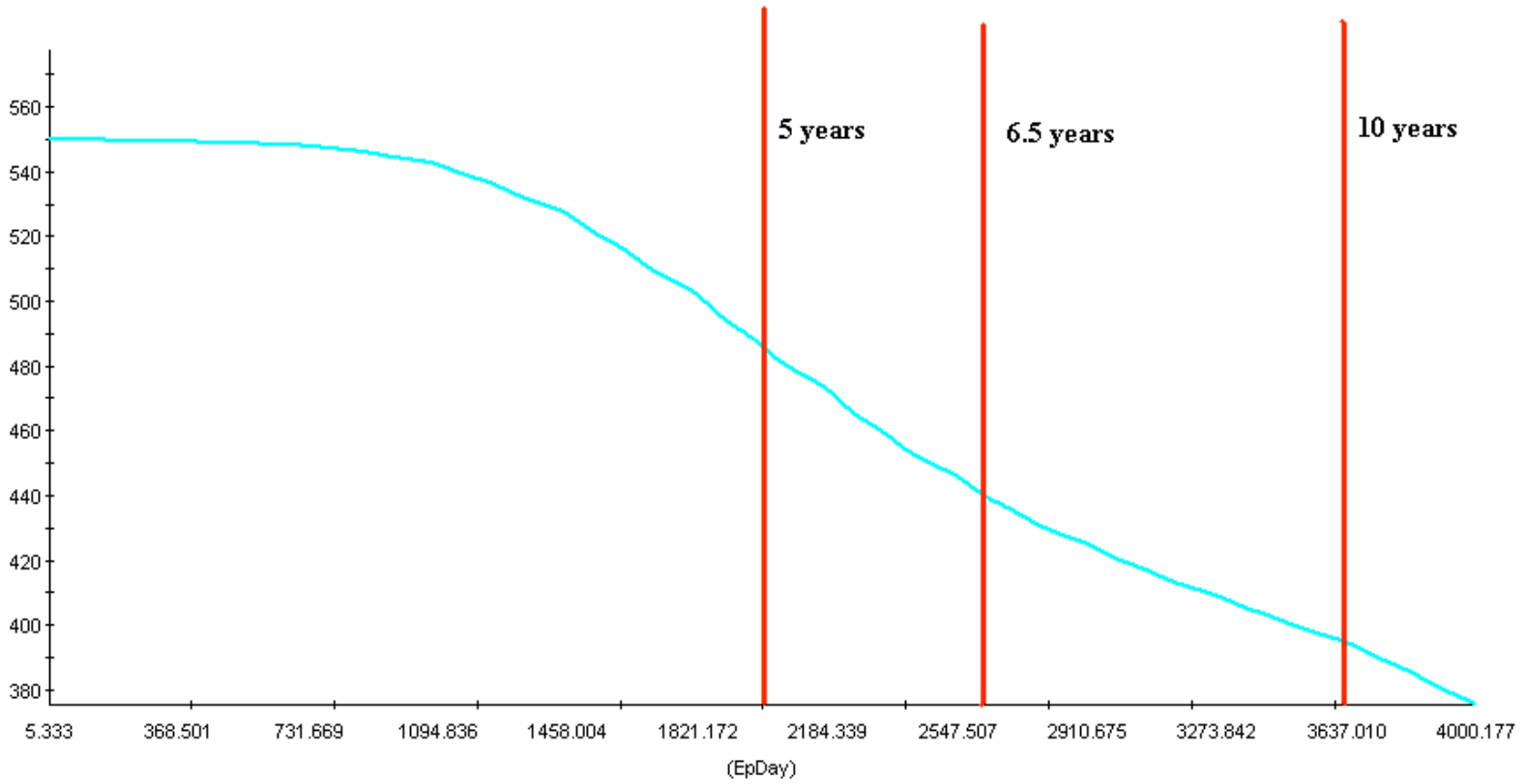
Orbit Profile

- Nominal orbit insertion is 565 km altitude, circular, inclined at 28.5°
- Hydrazine propulsion system will provide controlled re-entry **only**
- Orbit Decay Analysis (+2σ Solar Flux) performed by SAI, verified by Code 595
- Ground System required to support spacecraft in altitude range of 450 km to 575 km
- Launch Window Analysis not yet completed; launch window constraints TBS; prelaunch trajectory analysis not yet received

Orbit Decay Analysis from SAI



Orbit Decay Analysis from Code 595



De-Orbit Plan

- The GLAST mission will execute a de-orbit plan at the end of mission life.
- The current plan is to have 5 perigee lowering burns, each 5 minutes in duration, to get the altitude to 250 km.
- At that altitude there will be a final burn approximately 25 minutes in duration with a target altitude of 50 km to perform a controlled re-entry with a South Pacific Ocean target per the NASA standard 1740.14.

Propellant Budget

Maneuver	Delta-V (m/s)	Duration (sec)	Propellant Used (kg)	Remaining Prop (kg)
Separation				352.20
Apogee Burn 1	17.8	300.0	37.80	314.40
Apogee Burn 2	16.2	300.0	34.13	280.27
Apogee Burn 3	15.0	300.0	31.45	248.82
Apogee Burn 4	14.1	300.0	29.37	219.45
Apogee Burn 5	13.3	300.0	27.70	191.75
Apogee Burn 6	63.4	1612.5	129.72	62.03
ACS Pointing Error (5 deg)			1.43	60.60
Residual			3.00	57.60

Attitude Profiles

- Sky Survey Mode
- Pointed Observation Mode
- Safe Mode

Sky Survey Mode

- Z_B offset from Zenith by a specified rocking angle (+/- roll angle about X_B)
- Rocking angle in the range of 0° to 60°; nominally 35°
- X_B moves to keep the Sun line in the Z_B–X_B plane to maintain Sun along solar arrays
- Pointing accuracy 2° (1σ); 0.5° goal

Pointed Observation Mode

- Maintain Z_B inertially pointing at specified target
- Maintain Earth avoidance on Z_B , nominally 30°
- If desired, slew & point to a secondary target during Earth avoidance
- Pointing accuracy 2° (1σ); 0.5° goal

Observatory Safe Mode

- Provides a Sun-pointing, power-positive, thermally safe orientation
- Attitude errors and rates computed from SIRU, CSS & TAM data input

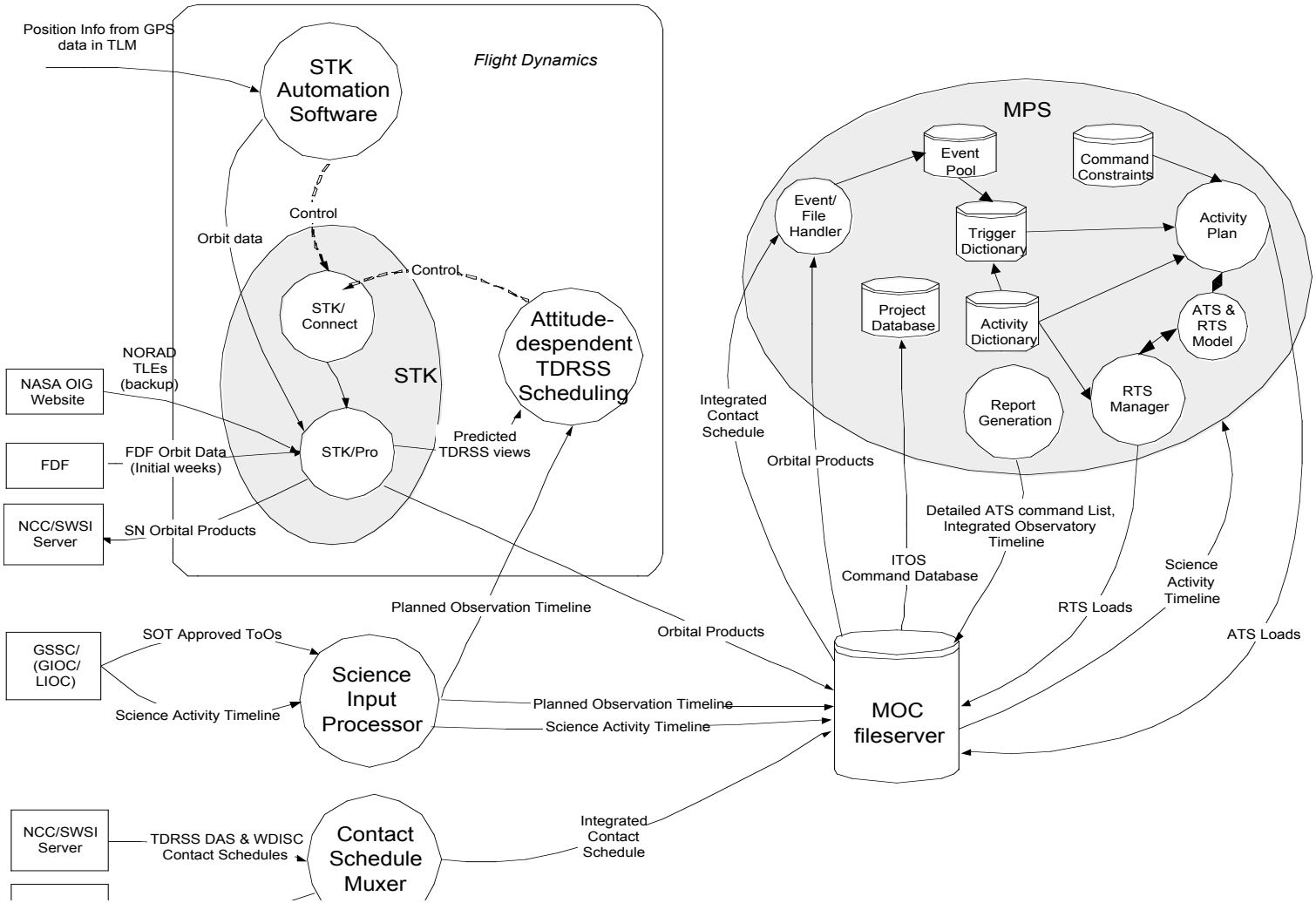
Network Services

- Primary telemetry communications is Ku-band via TDRSS, commanding via S-band
- Backup comm using S-band, USN (L&EO) and GN
  - USN sites: Dongara, Australia & South Point, HI
  - GN sites: Wallops and MILA(?)
  - No tracking from ground stations
- One-Way Doppler via TDRSS (GPS checkout & contingency support)

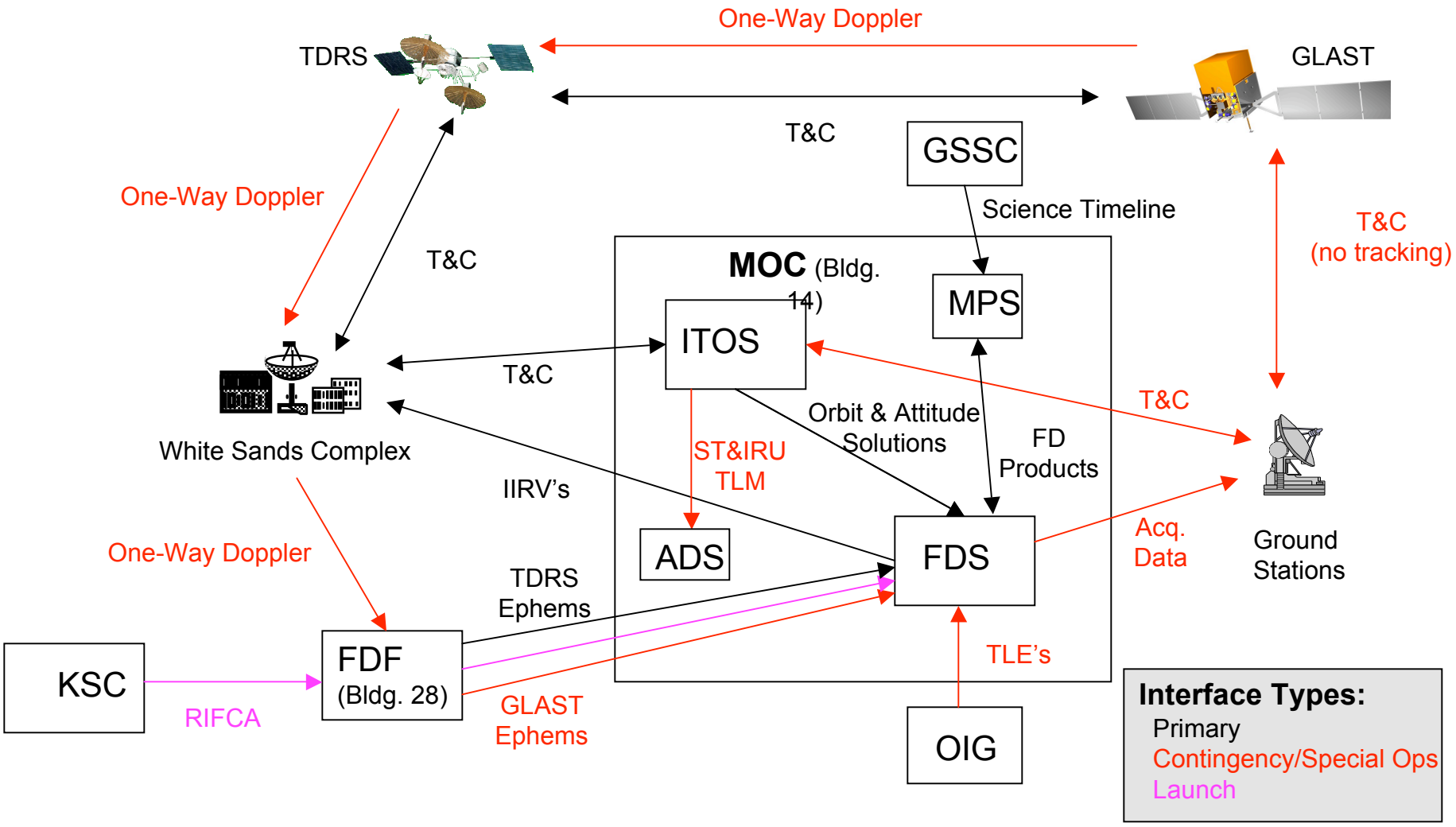
FDF Support

- Support provided via PSLA, submitted Oct. 20, 2003; revised Jan. 2004
- Provide the post launch orbit solution to the MOC within 1 hour after GLAST separation using RIFCA data from KSC/Boeing.
- For initial GPS checkout and contingency in case of GPS receiver failure, FDF will use DOWD for OD.
- The FDF will utilize the NORAD TLE sets for orbit contingency. The accuracy of the orbit data products provided to the MOC must be sufficient for acquisition only.

Mission Planning & Scheduling



GLAST Flight Dynamics Data Flow Diagram



FD Data Interface Notes

- FDF - Flight Dynamics Facility (under MOMS contract)
- RIFCA - Inertial Guidance Data from the Delta ELV, used for post-separation orbit determination & prediction
- Orbit Solutions from FDF based on RIFCA (post-launch) or TDRSS DOWD (GPS checkout/failure/outage)
- FDS - Flight Dynamics System (resides in MOC)
- Acquisition Data format is IIRV for TDRSS, Wallops, & MILA; TLE for USN ground stations
- ADS - Attitude Determination System
- Star Tracker (ST) and gyro (IRU) telemetry used for attitude/instrument calibration using software provided by Code 595

MOC-Based FD Software

- Omitron is tasked to develop Flight Dynamics System (FDS)
- Code 595 will provide consultation, analysis support, testing support
- Code 595 will provide the MOC with the Attitude Determination System (ADS)
  - MATLAB-based MTASS system
  - MOC will provide workstation(s) to host MTASS
  - Code 595 will provide MATLAB software and licenses
  - Code 595 will provide L&EO support and MTASS training to FOT

Flight Dynamics Requirements

- Flight Dynamics Requirements come from:
  - GLAST Ground Systems Requirements Document (GSRD); Level 3 Requirements
  - GLAST MOC Functional & Performance Requirements Document; Level 4 Requirements, linked to Level 3 Reqs.
  - GLAST Project Level Service Agreement (PSLA); FDF Requirements under the MOMS contract

Orbit Requirements

- The FDF shall provide orbit analysis support to the MOC for the pre-launch, and L&EO phases
- The FDF shall receive GPS telemetry data from the MOC
- The FDF shall perform orbit determination using the MOC provided GPS data
  - *This will be performed by an FDS system in the MOC instead of the FDF facility.*

Orbit Requirements - Launch

- The FDF shall receive the launch vehicle separation vector from KSC during launch
- The FDF shall provide orbit determination support using the launch vehicle separation vector

Note: Currently working with launch vehicle manager to receive RIFCA data in addition to a separation vector.

Orbit Requirements - Contingency

- The FDF shall provide predictive and definitive orbit products to the MOC
- The FDF shall perform orbit determination using TDRSS Differenced One-Way Doppler (DOWD) data provided by the SN
- The FDF shall perform orbit determination using NORAD Two-Line Elements (TLE)

Attitude Requirements

- The FDF shall receive attitude telemetry data from the MOC
  - *This will be performed by an FD provided system in the MOC instead of the FDF facility*
- The FDF shall validate the on-board computed attitude during the L&EO phase
  - *This will be performed by an FD provided system in the MOC instead of the FDF facility*
- The FDF shall perform attitude determination using telemetry data provided by the MOC within an accuracy of 1.0°
  - *This will be performed by an FD provided system in the MOC instead of the FDF facility*
- The FDF shall provide attitude validation results to the MOC
  - *This can be satisfied by using an FD display in the MOC facility*

GPS Short-Term Failure

- GPS dropout of 30 minutes or less
  - Orbit accuracy of 3.3 km maintained by onboard propagation from last valid GPS orbit state
  - Spacecraft clock propagated using OCXO oscillator from last valid GPS time

GPS Multi-Day Failure

- GPS dropout of 30 minutes to 3 days
  - Orbit solution accuracy in degraded mode
  - GNC subsystem can accept and propagate spacecraft orbital element uploads from the ground system
  - Two sources of ground-based orbit knowledge
    - Last valid GPS telemetry downlink
    - NORAD TLE's
  - FOT will begin scheduling TDRSS One-Way Doppler services

GPS Extended Failure

- GPS dropout of 3 days or more
  - FOT will schedule TDRSS One-Way Doppler services for DOWD
  - FDF will perform OD using GTDS and provide daily orbit solutions to the FOT
  - FOT will uplink daily orbital element sets to the spacecraft
  - All orbit accuracy requirements will be met (DOWD analysis will be presented)

DOWD

- Differenced One-Way Doppler (DOWD) will be used for verification of GPS solutions and can be used a contingency orbit determination method
- Requires scheduling simultaneous One-Way Doppler services with two non-collocated TDRS satellites
- S-band tracking via either of the 2 GLAST half-Omni transmitters (+X side or –X side)
- FDF performs orbit determination from TDRS tracking data using Goddard Trajectory Determination System; GTDS removes frequency bias from GLAST oscillator

DOWD ODEAS Setup

- GLAST in rocking mode, rocking angle = 30°
- TDRS Tracking Schedule from STK:

TDRS Pair	Pass Start (UTC)	Pass Duration (sec)
TDE & TDZ	3/21/2006 0:46:31	231
TDE & TDZ	3/21/2006 12:41:39	282
TDW & TDZ	3/21/2006 23:50:31	213
TDE & TDZ	3/22/2006 12:32:10	368
TDW & TDZ	3/22/2006 23:42:37	185
TDE & TDZ	3/23/2006 10:54:31	693
TDE & TDZ	3/23/2006 22:50:22	677

DOWD Analysis Results

- Definitive Position Error (72 hour arc)
  - Solar Flux = 105.0, Position Error = 52 to 212 meters
  - Solar Flux = 175.0, Position Error = 85 to 330 meters
  - Well within the GLAST orbit requirement of 3.3 km
- TDRS visibility excellent for all inertial pointing mode profiles
- TDRS visibility adequate in sky survey mode; visibility increases as rocking angle increases
- Existing GTDS software can use DOWD for GLAST orbit determination; no software modifications needed

DOWD Tracking Data Reqs.

- 2 passes per day with 2 non-collocated TDRS satellites
- Simultaneous One-Way Doppler tracking services to both TDRS satellites
- Minimum pass duration of 3 minutes
- Passes spaced from 10 hours to 14 hours apart

Ground-Based Orbit Tools

- STK will be used in the MOC
- Predictive orbit will be from either:
  1. Telemetered GPS state (time, position, velocity) using HPOP propagator
  2. FDF-supplied ephemeris
  3. NORAD TLE using SPG4 propagator
- Definitive orbit will be from either GPS or FDF
- STK Pro will be used for mission planning products
- STK/Astrogator will be used for re-entry maneuver planning

Ground-Based Attitude Tools

- No real-time attitude determination required
- Non-real-time attitude determination, attitude validation, and attitude calibration will be provided by Code 595 system (MTASS) in MOC
- Code 595 will provide L&EO attitude support and train FOT to use MTASS
- Attitude Prediction tool will be developed to allow attitude-dependent Ku-band TDRSS scheduling
  - Attitude prediction profile will be produced from the science timeline
  - Software provided by Omitron, validated by Code 595

Software Integration & Testing

- MOC developers will provide integration of FDS software
- Code 595 will deliver ADS for integration into MOC
- FDS, ADS, and FDF will be tested in GRT's to demonstrate that all FD requirements are satisfied
- End-to-End Tests, Ops Readiness Tests, Mission Simulations, and Launch Readiness tests will demonstrate operational readiness

Configuration Management

- GLAST Ground System CCB will control requirements, ICDs, PSLA
- MOC CCB will control element-level CI's
  - FDS, ADS, Attitude Prediction Software
  - Test Plans, User's Guides, Procedures, etc.

Code 590 Support Role

- Code 595 (M. Woodard) is involved in ground systems development, testing, and operations
- Code 595 support role is important, but to a lesser extent than for a typical GSFC mission
  - Orbit & Attitude Determination performed onboard
  - MOC developers providing mission planning systems
  - Code 595 will support L&EO operations, contingency operations
- Code 591 (E. Stoneking), 594 (N. Rioux), 597 (M. Underdown) also providing support

Code 595 Staffing Profile

- Staffing will include 1 senior engineer and 1-3 junior engineers
  - FY04 1.0 FTE
  - FY05 1.5 FTE
  - FY06 1.5 FTE
  - FY07 2.0 FTE
  - FY08 & → Contingency support only

Documentation

- GLAST Ground System Requirements Document (GSRD) – CCB approved 12/03
- GLAST MOC Functional & Performance Requirements Document – Draft 12/03
- GLAST PSLA – Draft 10/03, Update 1/04
- GLAST MOC/FDF ICD – Draft 2/04
- Operational FD Procedures – Draft 7/05
- ADS User's Guide - 7/05

Schedule

SDR	6/04	Mission Sims Start	5/06
TFA Trajectory	11/04	MOC Release 4	7/06
MOC Release 1	1/05	DTO Trajectory	8/06
Ops Peer Review	4/05	Launch R.T. #1	10/06
MOC Release 2	7/05	ORR	12/06
MOR	10/05	Ship to KSC	12/06
MOC Release 3	1/06	FMA Trajectory	1/07
PMA Trajectory	2/06	Launch R.T. #2	1/07
		Launch	2/07

Open Items

- Pre-launch trajectory expected in late 2004
- Launch window constraints not yet defined
- Propulsion system on-orbit validation plan not yet provided

Issues & Concerns

- No major issues or concerns
- Particular focus will be applied to the development of the attitude prediction tool

Acronym List (A-F)

- ADS Attitude Determination System
- CCB Configuration Control Board
- CI Configuration Item
- CSS Coarse Sun Sensor
- DOWD Differenced One-Way Doppler
- DTO Detailed Test Objectives
- ELV Expendable Launch Vehicle
- FD Flight Dynamics
- FDF Flight Dynamics Facility
- FDS Flight Dynamics System
- FMA Final Mission Analysis
- FOT Flight Operations Team
- FTE Full-Time Equivalent

Acronym List (G-J)

- GBM GLAST Burst Monitor
- GLAST Gamma-Ray Large Area Space Telescope
- GN Ground Network
- GNC Guidance Navigation & Control
- GPS Global Positioning System
- GSFC Goddard Space Flight Center
- GSRD Ground Systems Requirements Document
- GTDS Goddard Trajectory Determination System
- ICD Interface Control Document
- IIRV Improved InterRange Vector
- IRU Inertial Reference Unit
- ITOS Integrated Test and Operations System

Acronym List (K-O)

- KSC Kennedy Space Center
- LAT Large Area Telescope
- L&EO Launch & Early Orbit
- MILA Merritt Island
- MOC Mission Operations Center
- MOMS Mission Operations & Mission Services
- MPS Mission Planning System
- MTASS Multi-mission Three-Axis Support System
- NASA National Aeronautics & Space Administration
- NORAD North American Aerospace Defense Command
- OCXO Ovenized Crystal Oscillator
- OD Orbit Determination
- OIG Orbit Information Group
- ORR Operational Readiness Review

Acronym List (P-S)

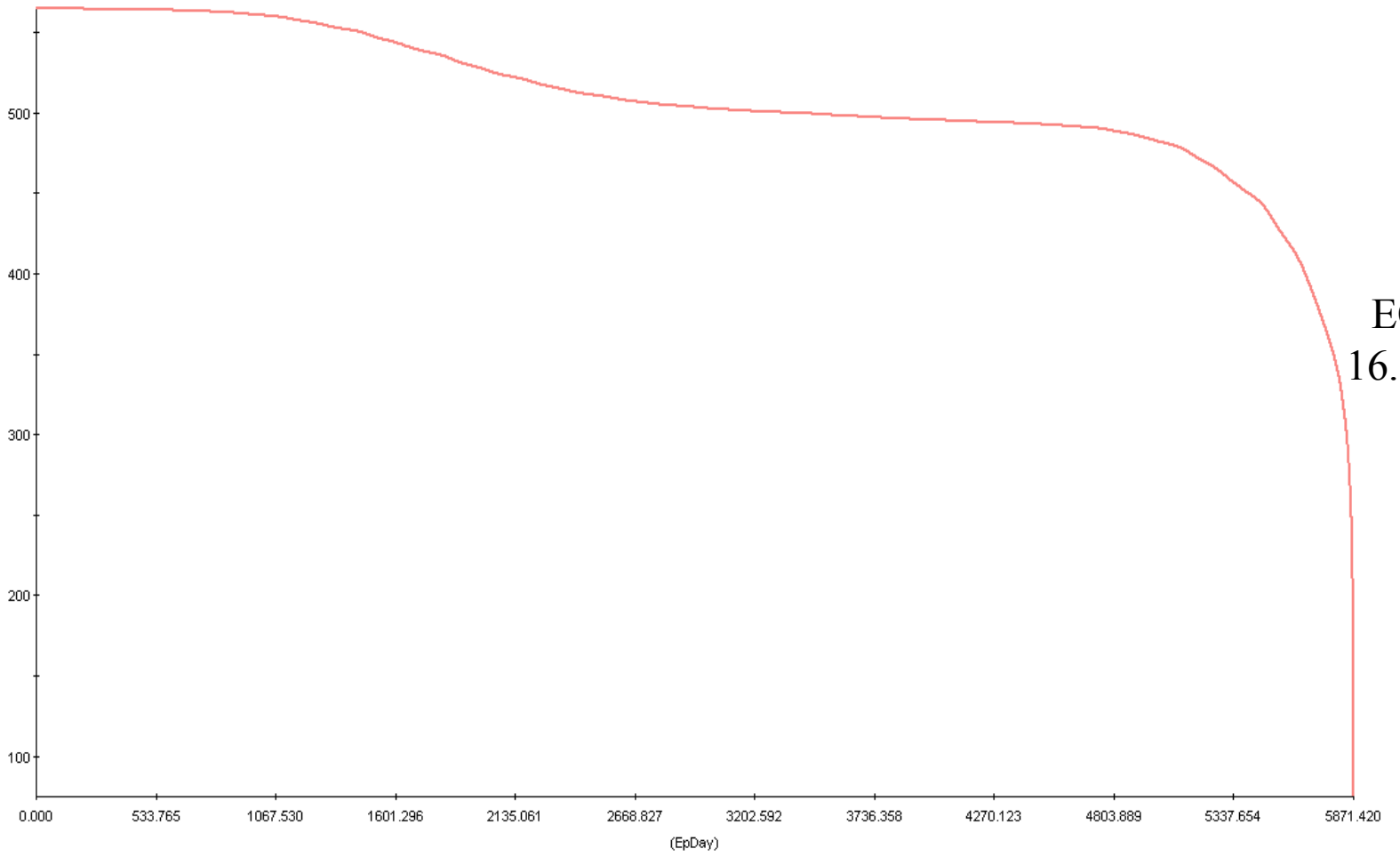
- PMA Preliminary Mission Analysis
- PSLA Project Service Level Agreement
- RIFCA Redundant Inertial Flight Control Assembly
- RFA Request For Action
- SAI SpectrumAstro Inc.
- SDR Systems Design Review
- SIRU Space Inertial Reference Unit
- SN Space Network
- ST Star Tracker
- STK Satellite ToolKit

Acronym List (T-Z)

- TAM Three-Axis Magnetometer
- TBS To Be Supplied
- TDE TDRS-East
- TDRS Tracking & Data Relay Satellite
- TDRSS TDRS System
- TDW TDRS-West
- TDZ TDRS-Z
- TFA Trajectory Feasibility Analysis
- TLE Two-Line Element
- TNT Tri-Nitro Toluene
- USN Universal Space Network

Backup Slides

GLAST Orbit Decay from 565 km



EOL at
16.1 years

Level 4 Requirements (1 of 5)

- The ITOS shall create sequential print files containing orbit position data.
- The ITOS shall create sequential print files containing attitude-related telemetry data.
- The MOC shall provide orbit and attitude-related sequential print files to the FDF.
- The MOC shall receive orbit products from the FDF as defined in the FDF-MOC Interface Control Document.
- The MOC shall integrate orbit sequential print files into the Flight Dynamics System.
- The Flight Dynamics System shall generate orbital predictions.
- The Flight Dynamics System shall use the J2000 Earth Centered Inertial (ECI) coordinate system.
- The MOC shall receive NORAD Two Line Elements (TLEs).
- The MOC shall integrate TLEs in the Flight Dynamics System.

Level 4 Requirements (2 of 5)

- The Flight Dynamics System shall generate IIRVs for TDRSS scheduling
- The MOC shall retain orbit solutions for the duration of the mission.
- The MOC shall allow viewing of orbit solutions.
- The MOC shall allow updating of orbit solutions.
- The MOC shall perform orbit propagation.
- The MOC shall perform orbit propagation with a minimum accuracy of 1 second for a 3-day prediction for Absolute Time Commands.
- The MOC shall perform orbit propagation with a minimum accuracy of 1 second for a 3-day prediction for event-based predictions.
- The MOC shall perform orbit propagation with a minimum accuracy of 0.1 degrees for a 3-day prediction for angle-based predictions.
- The MOC shall generate orbital products using propagated orbit solutions as specified in the *GLAST Operations Data Products ICD*.
- The Flight Dynamics System shall generate event reports for the MPS.
- The MOC shall use the science timeline to predict the observatory attitude.

Level 4 Requirements (3 of 5)

- The Flight Dynamics System shall generate predicted ground station and TDRS view periods for the Omni antennas.
- The Flight Dynamics System shall generate predicted TDRS view periods for the Ku antenna.
- The MOC shall generate spacecraft day/night predictions, including umbra and penumbra event times. The MOC shall generate predicted South Atlantic Anomaly (SAA) region entry and exit times.
- The MOC shall generate predicted ephemeris data for GLAST.
- The MOC shall generate predicted ephemeris data for TDRS satellites.
- The MOC shall generate definitive ephemeris data for GLAST.
- The MOC shall model ground antenna masking constraints to determine access times.
- The MOC shall model observatory antenna masking constraints to determine access times.
- The MOC shall model sun-line RF interference.

Level 4 Requirements (4 of 5)

- The MOC shall determine the times when the observatory has access to the SN.
- The MOC shall model the predicted observatory attitude when in sky survey mode to determine SN access times.
- The MOC shall model the predicted observatory attitude when in a pointed observation mode to determine SN access times.
- The MOC shall temporally model observatory yaw flips.
- The MOC shall account for yaw flips when determining TDRSS access times.
- The MOC shall temporally model observatory earth limb traces.
- The MOC shall account for earth limb traces when determining TDRSS access times.
- The MOC shall temporally model observatory Ku-band antenna slews.
- The MOC shall account for observatory Ku-band antenna slews when determining TDRSS access times.

Level 4 Requirements (5 of 5)

- The MOC shall model the predicted ephemeris to determine SN access times.
- The MOC shall provide S/C orbit information to the SN for contact acquisition.
- The MOC shall provide the orbital elements in the form of improved interrange vectors (IIRVs) to WSC via SWSI for TDRSS contact acquisition generation.
- The MOC shall provide the capability to schedule two simultaneous TDRSS One-way Doppler services to support orbit determination.
- The MOC shall schedule all backup ground station contacts with the observatory for command uplink and telemetry downlink.
- The MOC shall model the predicted ephemeris to determine backup ground station access times.
- The MOC shall provide orbital elements to the backup ground stations for contact acquisition.
- The MOC shall receive ground station contact schedules from the backup ground stations.